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High Frequency (HF) Automatic Link Establishment (ALE)

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SUMMARY

As a result of Independent Exploratory Development (IED) funding of an investigation of High Frequency (HF) Automatic Link Establishment (ALE), the principal investigator on this task has had the opportunity to participate in Federal-level ALE standards development and related test and evaluation planning for proof-of-concept testing of these standards. At the time of Naval Ocean Systems Center's (NOSC) involvement in these activities, there was no Navy, Federal-level participation. Since representatives from virtually all agencies of the U.S. Government participated, it appeared to be an effective starting point for the investigation of HF ALE. As a result of this participation, and the fact that NOSC had earlier purchased two Harris ALE Controllers (RF 7210) designed to meet the ALE Federal-Standard (FED-STD) 1045, the Navy participated in the 1990 FED-STD Over-The-Air test. The new standards, FED-STD 1046 (networking) and 1049 (link protection) were to be tested under the test plan. The Navy was included in the test plan and provided two nodes for the test: one at NOSC San Diego and the second at NOSC Hawaii.

During the FED-STD test period, NOSC was also able to conduct, on a noninterference basis, Navy-Only testing over three 16-hour periods. These tests took place on the last days of the test period. The Navy-Only test data have been analyzed and are presented in section 3.0 of this report.

KEY FINDINGS FROM NAVY-ONLY TESTING OF FED-STD ALE

The FED-STD ALE performed quite well using a double hop HF propagation path over a large Pacific Ocean area. The great circle distance between the two Navy nodes was 2610 miles. A 35-foot whip antenna was used at NOSC Hawaii, and a dual 17-foot whip was used at NOSC San Diego. Both systems used Harris HF transceivers (RF 350 K) with 100-watt output radio frequency (RF) power and RF-382 fast-tuning antenna couplers. Some particularly noteworthy findings from this investigation included the following:

A. The FED-STD ALE data transmission modes performed flawlessly at its 62.5 bits-per-second (bps) data rate in both point-to-point and relay modes when links were established.

B. Voice reception using ALE frequency/channel selection generally performed poorly at one or the other of the two Navy nodes. However, there were times when both nodes had excellent voice copy. Data analyzed in this report agree with ALE operator experience using voice communications. More sophisticated HF antennas and higher transmitted RF power could have improved this performance.

C. Based on the reported results of earlier ALE testing performed by the Joint Interoperability Test Agency plus the Navy-Only test data, it is estimated that over a significant amount of the available test time there were several frequency channels that could support 2400-bps data transmission. Testing is required, using the foregoing communication equipment and a robust data modem to precisely define the actual BER performance. The graphical presentation of the data in this report should assist the reader in obtaining a quantitative assessment regarding channel availability. To achieve a 2400-bps capability, a robust modem such as the Harris RF 3466 or RF 5254C is required. The method to be used in switching the modem from one channel to another to maintain a minimum BER, at this continuous data rate for the longest time, requires a design study.

D. The method used in the FED-STD ALE for channel ranking to select the best HF channel, using the composite Link Quality Assessment (LQA) criteria, is flawed. From the test data, it has been determined that several selections using essentially the same LQA can result in instances where the same signal-plus-noise-to-noise ratio (Sinad) existed at both nodes, while at other times Sinad results at each end of the link could have a

13- to 16-dB disparity. However, as will be seen in this report's recommendations regarding ALE use on major combatant ships, this flaw is not of serious concern to the Navy.

E. The most significant finding in the testing of the FED-STD ALE relates to its use of a single HF frequency for point-to-point linking between nodes. This is a serious limitation in the employment of the FED-STD ALE aboard major combatant surface ships of the Navy. On these ships, the shipboard electromagnetic interference (EMI) environment is such that the ALE will be constrained to use limited reception regions in the HF spectrum. This limits the number of receive frequencies available for LQA and linking. Outside of these receive regions, the node-to-node three-way handshaking, used for the exchange of Sinad and PBER data needed for ALE LQA matrix construction, would be significantly degraded by high shipboard EMI levels. On the other hand, because of lower EMI levels at a shore node, the HF frequencies that a shore node might like to receive will cover a much larger unrestricted spectral portion of the 2- to 30-MHz HF band. The ship may not be troubled in transmitting to the shore station at any of these desired shore-receive frequencies. The conclusion is clear: the Navy requires a two-frequency ALE that will allow receive frequency flexibility needed to accommodate its shipboard EMI environment and one that will not penalize shore reception capability.

With the two-frequency ALE concept, the present difficulties cited earlier disappear, relative to the Sinad disparity that can exist between both nodes for a given LQA. Instead, each node will seek receive frequencies that will maximize the measured Sinad and, thus, minimize the BER levels in received data. Additionally, with a two-frequency ALE system, a capability for full duplex data communications also would be possible. A separate HF receiver and transmitter would be the HF radio equipment configuration if full duplex operation is to be used. HF transceivers that have transmit and receive frequencies remotely controlled by the ALE controller could operate in a dual-frequency half-duplex mode. More will be said on this subject in the next part of this report.

ILLUSTRATION OF POSSIBLE FUTURE ADVANCED TWO-FREQUENCY ALE CONCEPT

An ideal point-to-point, two-frequency ALE configuration would use the ALE to control the transceiver's receive and transmit frequencies in a dual frequency time division multiplex (TDM) mode. The transceiver at each node would be performing in a TDM-programmed two-way sounder operation over the HF band (except for transmit frequency exclusions). During each node's transmit frequency slot, it would advise the other node of the Sinad value of the HF frequency received in its previous receive frequency TDM slot. The data exchange would allow each node to rank the transmit frequencies based on the receive node's Sinad data. When a two-frequency ALE is to be performed for the purpose of verifying the link quality using the two frequencies or for the transmission of voice or data, this could be done automatically using a two-frequency instead of a single-frequency ALE/LQA matrix.

At the next more sophisticated level, after a link quality verification of the selected frequencies, the best set could be handed over to the transmitter and receiver at each node that is to be used for full-duplex, high-speed data communication. The advent of broadband HF transmitting systems, such as the AN/URC 109 or the Harris RF 1170, appears to allow an ALE transceiver's RF transmission over the HF band to go on concurrently with the HF transmission of 2400-bps data. If this simultaneous transmission can be properly achieved over the HF band, an ALE update of the transmitter and receiver to the best HF frequencies could be performed in near-real-time. The purpose of the update being to maintain continuous 2400-bps data reception at the lowest possible BER.

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TABLE

1.0 INTRODUCTION

This report presents the findings developed as a result of a Navy-funded Independent Exploratory Development (IED) investigation. This investigation allowed the testing of a new processor-based communication technology created to improve high frequency (HF) communications. The new HF communication technology that was examined is called Automatic Link Establishment (ALE) and is in accordance with Federal Standard (FED-STD) 1045 and Military Standard (MIL-STD) 188-141A. This report does not provide a complete textbook treatment of this subject. What is presented is a discussion of aspects of the subject necessary for an understanding of the study findings and use of this technology on Navy combatant warships to meet general command, control, communications, intelligence (C^3I) requirements. Because this report is unclassified, special C^3I requirements that might be of interest in the use of non-FED-STD HF ALE techniques are not discussed.

The first part of this report is an introductory technical discussion of various aspects of HF FED-STD ALE. The last part addresses the test data analysis and results. Test data were obtained by Naval Ocean Systems Center (NOSC) during a Navy-Only test phase performed in conjunction with Navy support of a FED-STD Over-The-Air testing. During the Navy-Only test, both NOSC San Diego and NOSC Hawaii were active as data collection test nodes, and they used the same ALE/networking/ protection protocol and equipment as when they were part of the FED-STD test network. This report attempts to assess the new HF ALE capability that satisfies FED-STDs 1045, 1046, and 1049 requirements in terms of its strengths and weaknesses for Navy communications.

1.1 GENERAL COMMENTS ON BENEFITS FROM IED PROJECT

Prior to presenting the details of this investigation, it is appropriate to comment on the overall benefit derived from the Navy IED program that funded this investigation of HF ALE.

The funding of this IED task has permitted the following:

A. NOSC Principal Investigator (PI), James P. Rahilly, to participate and become a member of both Government-wide Federal Standards Development and Test and Evaluation Working Groups. The principal concern of these working groups to date has been the development and testing of FED-STDs 1045, 1046, and 1049.

B. Meeting and exchanging technical information with Naval Research Laboratory (NRL) engineering personnel who are known for their expertise in HF communications. This exchange established a working relationship between NRL and NOSC to improve Navy HF communication by the possible use of HF ALE.

C. Travel and technical discussions with contractors (CNR and Harris Corp) to determine in what way HF ALE techniques might be used to improve Navy HF C^3I communications.

D. Access to FED-STD ALE documentation and test reports to become better acquainted with the background and state of FED-STD HF/ALE.

E. A working relationship with FED-STD participants has led to NOSC being accepted as a member and asked to provide test nodes for Over-The-Air FED-STD Proof-Of-Concept (POC) testing.

F. Obtaining ALE test data and Navy test results, which show the HF/ALE performance over a 2610-mile ocean path. These results (section 3.0) were obtained by NOSC during the FED-STD testing period on a noninterference basis using IED funding.

G. Development of concepts for integrating the benefits of the FED-STD ALE with the capabilities of high-performance modems, such as the Harris 3466 or 5254C. Because development in this area may allow a significant improvement for the Navy in the availability of HF High data rate (2400 bps) communication capabilities, this has been recommended for future IED funding.

1.2 BACKGROUND AND OBJECTIVES

Because establishing and maintaining HF long-haul communication links by the Navy currently requires the expenditure of much time and effort by skilled Navy manpower, due to the vagaries of HF propagation, the arrival of satellite communication has been generally viewed as a welcome communication alternative. The advantages in using satellite communication for long-haul communications has, over the years, caused a decrease in Navy interest in HF communications. Consequently, there is a Navy reluctance to stress training of HF communicators to develop and improve operator proficiency. The resultant reduction in operator HF proficiency has caused even less interest in using HF for long-haul communication. HF ALE technology offers a promise for providing a solution to the above Navy difficulties in using HF. As the name implies, the process of providing a two-way path or link for HF communications is implemented in a fully automatic manner. No operator is needed to select HF frequencies and establish an HF link between the two nodes. This is achieved in the ALE system by its performing a real-time HF signal reception assessment at each node. This assessment includes the quality of HF propagation and HF receiver noise/interference when HF communications is to take place. As a result of the exchanges of information between two nodes, usable communication links can automatically be established. With these assessments, the FED-STD ALE equipment can identify, from a set of allowed HF transmit frequencies in a point-to-point (PTP) situation, the most desirable frequency channels to use. In accordance with the FED-STD 1045, or its military version MIL-STD 188-141A, the ALE uses the Link Quality Assessment (LQA) as a method for ranking the allowed frequencies/channels. A three-way handshake between the two nodes allows the exchange of measured signal-plus-noise-to-noise (Sinad) and pseudo-bit-error-rate (PBER) measurements. Using these measured values, a single composite LQA value is developed that ranks the performance of the point-to-point (PTP) link between the two nodes, at each of the available usable channel/frequencies. More will be said on this subject later in this report.

What is now the ALE standard (FED-STD 1045) began development in 1986. The FED-STD Test and Evaluation working group has been chaired by a representative from the Defense Communication Agency. The chairman directed in 1988 that a series of POC Over-The-Air tests be performed to validate the FED-STD 1045 ALE standard. These tests were done by the Joint Interoperability Test Center (JITC), at Fort Huachuca, AZ. The tests used an ALE system produced by the Harris Corp in accordance with the FED-STD 1045 ALE standard. This equipment was used for POC testing, and the results were reported by the U.S. Department of Commerce (1988). Prior to the Over-The-Air testing, laboratory simulations were conducted at the Institute of Telecommunications Sciences (ITS), Department of Commerce Laboratories in Boulder, Colorado. These and other tests were performed between competing ALE approaches (Mitre and Rockwell/Collins ACP). Later, simulation tests were made on the final ALE configuration prior to the 1988 Over-The-Air testing.

Because the ALE system uses a digital processor for its various functions, it therefore possessed a capability for extensive addressing and special calls for network operation employing up to 15 nodes. FED-STD networking protocols were later defined in a new networking standard, FED-STD 1046. The HF FED-STD ALE is intended to serve virtually all Federal agencies including Department of Defense (MIL-STD 188-141A), the Justice Department, U.S. Coast Guard, and the Central Intelligence Agency. It is, therefore, necessary that the Link Protection modules, provided by National Security Agency, be used to prevent unauthorized access or spoofing of operational links. This requirement has been addressed in the FED-STD 1049, the *Link Protection Standard*.

The incorporation of the new protocol for FED-STDs 1046 and 1049 into the POC ALE controller has been completed recently by the Harris Corporation. These two new FED-STD areas, as well as certain previously untested ALE areas of FED-STD 1045, were tested during August 1990 in laboratory simulation tests at ITS Boulder, CO. This was followed by Over-The-Air tests of these new standards during September.

Since NOSC already had procured two RF 7210 ALE controllers, designed to FED-STD 1045, the Center proposed to participate and support the new FED-STD Over-The-Air tests by providing two Navy test nodes. One of these nodes was at NOSC San Diego and the second was at NOSC Hawaii. The Navy objectives were, first, to be represented in these Federal tests and, second, to determine how FED-STD 1045 ALE developments could support Navy HF communication needs. The Navy-Only tests were conducted to satisfy the second objective. The results of the Navy-Only part of this testing is contained in section 3.0 of this report.

2.0 TECHNICAL DISCUSSION OF AUTOMATIC LINK ESTABLISHMENT

2.1 FED-STD ALE

The FED-STD ALE belongs in the category of Non-Frequency Hopped ALE. In this ALE, the basis for the decision to use a particular HF frequency is determined from its LQA values. The LQA values are assigned to locations in an ALE matrix that relates to the HF frequency channel used. These matrix data are collected when the selected HF frequency permits a linkage of the two nodes to occur. When the link quality drops below a certain level, at the selected RF frequency, a change in selected HF frequency is made based on the next highest LQA value in the matrix.

In the ALE FED-STD 1045, a single LQA value is defined for a link between two nodes, using a particular channel (frequency). This is made by a combination of independent measurements at each node. The measurements made are the Sinad of the received signals and a PBER of the received ALE word. A duplicate matrix of LQA values is at each node showing the LQA ranking of each possible HF transmit frequency.

2.2 FED-STD ARCHITECTURE AND PROTOCOLS

The FED-STD 1045 ALE controller provides for modulation and demodulation functions using an M-ary frequency shift keying (FSK) phase continuous signaling that selects any of one eight tones in a 3-kHz band to transmit 3 bits. The FED-STD ALE architecture is built around a 24-bit ALE word that can have a number of different formats. All 24-bit ALE words are 2:1 encoded using Golay Forward Error Correcting coding to yield 48 transmitted bits per ALE word. To minimize multipath and Doppler effects, interleaving is performed between the original 24 data bits and 24 encoding bits. In a further effort to minimize intersymbol interference effects, a 49th "stuff bit" has been added and, therefore, the final HF transmission actually uses 49 bits for each ALE word transmitted. Each 49th bit word is repeated three times. Upon reception, the 49th "stuff" bit is discarded, and each of the three receptions is separately deinterleaved and decoded to yield three received versions of the ALE word. Next, a two out of three majority vote decision is made on a bit-by-bit basis between the three received ALE words to yield the 24-bit ALE word. The PBER is developed during the majority vote process based on those instances when any lack of agreement is exhibited between the 24 bits contained in each of the three received ALE words. Because the basis of the BER assessment is derived from the majority vote process just described and not by a measurement relative to the actual transmitted bit stream, it is referred to as a pseudo BER measurement or PBER.

The structure of the 24-bit ALE words allows different word formats for various purposes such as commands (three bits), LQA data collection, different data transmission modes, and selective call signs/addresses. The LQA word format is used for reporting between the nodes the Sinad and PBER values used in the final determination of the LQA value for the link.

2.3 IMPLEMENTATION OF FED-STD ALE

FED-STDs 1045, 1046, and 1049 have been implemented by the Harris Corporation in the Harris RF 7210 ALE controller. The Harris Corporation has made these changes while under contract with the Federal Emergency Management Agency (FEMA). Earlier, NOSC had, independently, procured two RF 7210 controllers from the Harris Corporation. Because of NOSC's willingness to provide two Navy test nodes for the FED-STD Over-The-Air testing, these Navy ALE controllers were upgraded, at no cost to the Navy, to include the new FED-STDs 1046 and 1049 capability.

During the week of 6 August 1990, two NOSC engineers from Code 824, P. Donich and K. Owens, plus two engineers from Code 951, J. Ramos and P. Francis, were trained at the ITS, Boulder, CO, facility to operate the newly upgraded controllers. These NOSC personnel did an outstanding job in manning the NOSC FED-STD test nodes during the September Over-The-Air testing. Additional excellent test support was received from other engineers, including S. Barnett of Code 951. In particular, P. Donich provided valuable assistance in the personal computer (PC) processing of the collected data.

2.4 SINGLE HF FREQUENCY POINT-TO-POINT ALE

The FED-STD ALE concept is based upon acquiring data on HF propagation and signal reception measurements using HF sounder concepts. The quality of the received HF frequency at one node, if allowed by link conditions, is measured and communicated back to the other node.

By performing this process bidirectionally, both nodes possess the information needed to allow an assessment of link quality at each frequency channel. In doing this, the ALE uses the so-called three-way handshake. One node initiates a call to the other node on a particular prearranged HF frequency. The other node receives and measures the quality of the received signal, and now transmits back to the initiating node on this same frequency. If reception can occur at the initiating node, the signal quality information can be received from the other node. The initiating node, if it can receive on this frequency, not only knows the quality of the reception at the other node but is able to measure the quality of the reception of the signal transmitted from the other node. The initiating node now transmits on this same frequency to the other node to inform it of the quality of its received signal reception. Now both nodes have the same information regarding how well each did while receiving on this HF frequency. This process is repeated over other preselected frequencies to develop a matrix of frequencies versus link performance levels. In the FED-STD ALE, a composite LQA is developed for each permitted HF frequency/channel. Because the communication channel is over a specific linking frequency, the term channel is used synonymously with HF frequency.

There are disadvantages to the above mode of operation, which albeit provides the simplest suite of ALE radio equipment. Certain of the disadvantages in single HF frequency operation will be brought out in detail in the section of this report that discusses the results of the data analysis. However, two of the problems experienced will be discussed here.

The first of these relates to the inability of two nodes to link when it is not known that the other node is trying to call you. When both nodes are transmitting at the same time, on the same frequency, a link cannot be established. Unless there is some other way of communicating to each other, this situation could go on a long time under the belief that propagation difficulties are blocking the linkup. One way of defeating this problem is the discipline of the clock. This procedure would allow a node to transmit only in certain time frames. This clearly imposes an operational restriction by decreasing communication flexibility in the use of the system. Another way to avoid this problem is by requiring a node to go through the scan receive mode so it may become aware that someone is calling before it starts transmitting the call.

From the standpoint of Navy operational use of ALE on board a major combatant surface ship, the single frequency LQA value would suffer when the ship node receive frequency was in a spectral region of high electromagnetic interference (EMI). A frequency that may be the best selection for a shore station might be in the worst part of the HF spectrum for reception on the ship because of EMI. What is needed to deal with this environment is the maximum flexibility in the choice of HF frequencies in each direction. One other advantage is that with such a two-frequency link it would avoid the previous problem discussed and would also allow optimum frequency selection for full duplex data communications.

3.0 ALE POINT-TO-POINT NAVY TEST RESULTS

NOSC support of the FED-STD Over-The-Air POC testing was performed in accordance with the approved test plan of Federal Emergency Management Agency (1990).

The scheduled testing was conducted over a 9-day, 8-hour-per-day period. Testing concluded on 20 September 1990. During the testing the JITC at Ft. Huachuca, AZ, acted as net control and test director. There were six ground nodes in the test and one airborne node (for 3 test days only), as shown in figure 3-1. Much of the FED-STD testing used various networking call signs and network configurations. Under the network testing, data collection at each node was naturally limited. Consequently, it was felt that an effort should be made by the Navy to significantly increase Navy data collection. This was needed to enhance Navy knowledge of the ALE performance relative to HF propagation/system reception performance. This was achieved during the 16 hours when no FED-STD testing was planned on each of the last 3 test days. This period was used for Navy-only ALE testing. The results developed from this testing are discussed in the following sections.

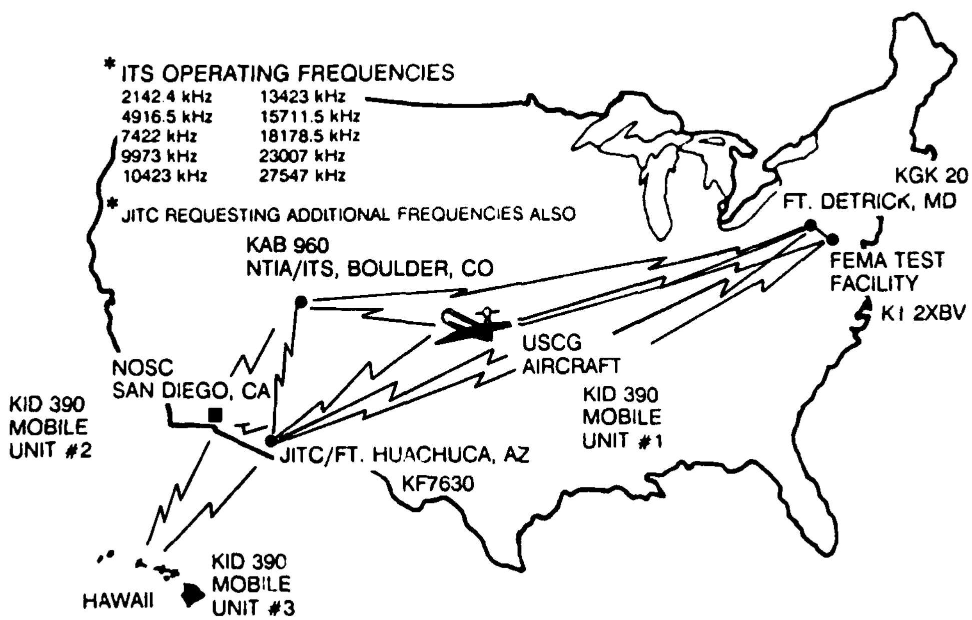

Figure 3-1. Test nodes and HF frequencies for FED-STD over-the-air testing.

3.1 NAVY TEST SCENARIO

To take advantage of the 16 hours Navy-Only test time available each day and still have manpower available to support the FED-STD testing for the rest of each day, advantage was taken of the fully automatic LQA feature in the ALE equipment.

In this automatic LQA mode of operation, one node initiates the call and selects a channel transmit frequency, starting with the highest channel number, in this case channel 10. A three-way handshake then is performed between the two nodes, if the Sinad and BER are at an acceptable level at each node. At the completion of the handshake, both nodes will have obtained from its counterpart the measured value of its signal parameters (Sinad and PBER) as received and measured by the distant node. Figure 3-2 shows an example of report back data taken from the data logger during testing. This report is available at each node using the appropriate Sinad and PBER values and composite single LQA value associated with these measurements. Figure 3-3 shows the equipment as installed at one of the Navy nodes. The transceiver, right, is the Harris RF 350K, and the RF 7210 ALE Controller, left, is below the Harris Pre- and Post-Selector filter system. The Data Logger PC is on the left with the monitor showing the LQA format presented earlier in figure 3-2. In the automatic LQA process, the allowable frequency channels are examined sequentially starting with the highest channel number (i.e., highest HF frequency). In the FED-STD testing, 10 channels were used. The respective HF frequencies are shown on figure 3-1.

Data collected during each Navy-Only test day were stored, using the data logger PC, on a floppy 5-1/4-inch disk. Usually, the data collected amounted to about 128K of data each day. These data were analyzed later after being entered into another PC with spreadsheet and three-dimensional data display programs. The output of the data analysis was the graphical presentations shown later in this section.

```
  C:19SEPT.SAN         P27 L44 C01 Insert Align                 Large-File
L----!----!----!----!----!----!----!----!----!----!----!--------R
                                                                         <
Raw Channel Data:         Received Score                 Measured Score  <
                          --------------                 --------------  <
Signal to Noise ratio - SINAD:  17 dB                    SINAD:   30 dB  <
Pseudo Bit Error rate - PBER:  0.0070                    PBER:   0.0000  <
Relative Multipath    - MPATH:   ----                    MPATH:    ----  <
                                                                         <
                          Channel score: 097                             <
                                                                         <
Time: 02:46:14                                                           <
Channel Number: 07    Transmit Frequency: 15.711500 Mhz  Transmit Mode: USB  <
                      Receive  Frequency: 15.711500 Mhz  Receive  Mode: USB  <
                                                                         <
Raw Channel Data:         Received Score                 Measured Score  <
                          --------------                 --------------  <
Signal to Noise ratio - SINAD:  18 dB                    SINAD:   18 dB  <
Pseudo Bit Error rate - PBER:  0.0000                    PBER:   0.0000  <
Relative Multipath    - MPATH:   ----                    MPATH:    ----  <
                                                                         <
                          Channel score: 084                             <
                                                                         <
Time: 02:46:32                                                           <
Channel Number: 06    Transmit Frequency: 13.423000 Mhz  Transmit Mode: USB  <
```

Figure 3-2. Printout of ALE data logger output.

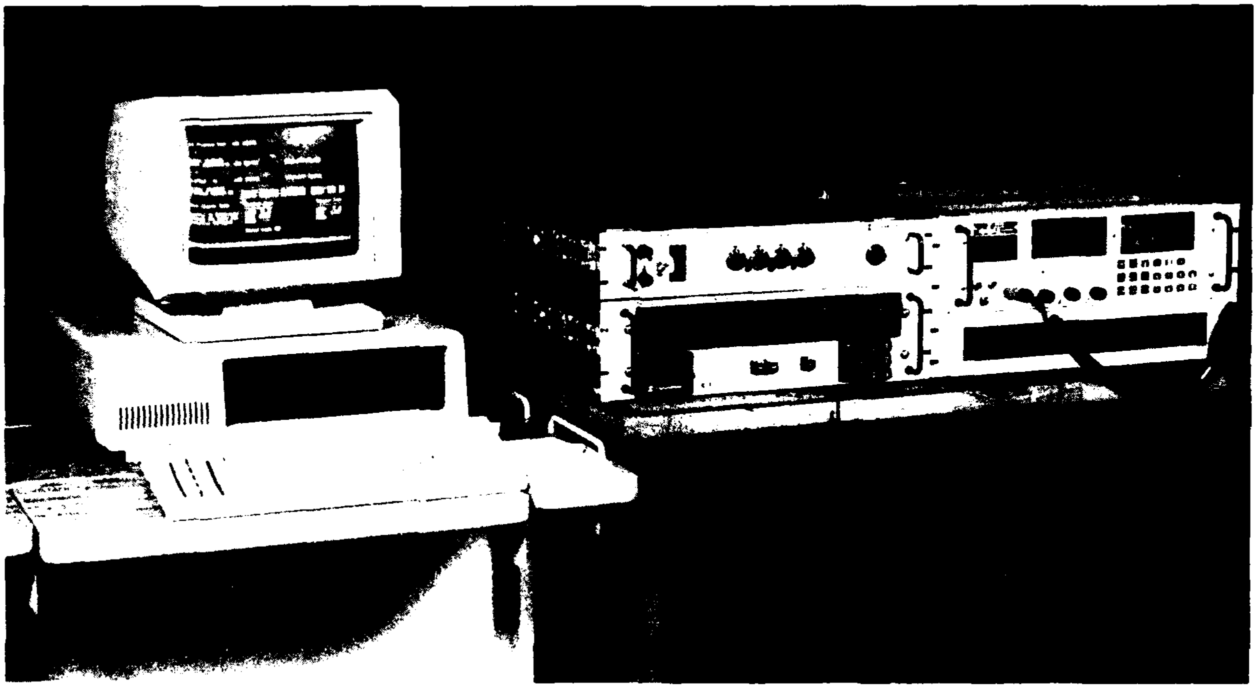

Figure 3-3. HF radio equipment plus ALE controller used for testing.

3.2 OVERVIEW OF NAVY TEST FINDINGS

The comments that follow are directed only at Navy point-to-point operation, i.e., two Navy nodes linking using ALE. The FED-STD test results related to networking performance and link protection capability will be addressed in the official FED-STD Over-the-Air test report to be published by the JITC.

In a sense the Navy-Only tests, with the exception of the use of the long haul over ocean path, repeat some of the FED-STD testing conducted in 1988 and reported in U.S. Department of Commerce (1988). The Navy was not involved in any of this earlier ALE testing of the FED-STD 1045; therefore, this seemed like an excellent opportunity for an assessment by the Navy of the capabilities of the FED-STD ALE. Of particular interest, from an applications standpoint, was the possible role of ALE in the selection of the best frequencies for ship/shore transmission of 2400-bps data using robust data modems, such as the RF 3466 or RF 5254C.

Since FED-STD ALE links are established over a single frequency channel. Full duplex operation is not possible and some form of time division use of the single channel would be required to exchange high-speed data in both directions. This, although restrictive, is not necessarily the crucial issue. During the testing, a more important concern became evident. This was related to the existence of the ambiguity discovered in the test results in channel selection based on the use of the FED-STD LQA criteria. The LQA matrix in the ALE controller allows a ranking of channels, using LQA values, that would determine the selection of transmit frequencies from the most desirable to the least desirable. Data collected during this test revealed that this channel selection based on LQA can result in significant disparity in terms of the actual Sinad performance at each node. Table 3-1 shows a few examples of data collected that illustrate this disparity. Note from these data taken at the times shown that on 20 September at 6:16:50Z (11:16 PM San Diego and 8:16 PM Hawaii time), at a value of LQA=93 on channel 5, a 21-dB Sinad value existed at both ends of the PTP link. This condition would allow the same communication performance at each end of a data link. Also note on this same day that at LQA=91 and LQA=94 the level of disparity between both ends of the links is in the range of 12 to 13 dB. Additionally, if the LQA=93 level had been selected, the lowest node Sinad performance would be a 5- to 6-dB improvement over the values associated with LQA=91 or 94. It may also be noted from this table that on 18 September the maximum LQA level was attained, i.e., 120. At this LQA value, both nodes had the same maximum Sinad value of 30 dB. At an LQA=107, it can be seen that one node had a 30-dB limit value of Sinad and the other node Sinad was 8 dB lower. The maximum difference in Sinad value at the two nodes was found in test data to occur on 19 September (10:17:47) and to be 16 dB. In this case, the LQA=40 and one node had a Sinad=20, while the other node had a Sinad=4.

It is concluded from these data that at the mid to high values of LQA the numerical LQA value provides, by itself, no insight as to the possible disparity in reception performance at each end of the link. At LQA values in the neighborhood of 90, the data show a 12-dB swing in Sinad measure of signal reception quality can occur at a particular node. At lower LQA values, the swing in Sinad could be as great as 16 dB.

Table 3-1. LQA versus Sinad comparisons.

Date/Time	LQA Value	Sinad from Node #1 / Sinad from Node #2	Sinad Difference
18 Sept/ 09:02:2Z	120	30 dB / 30 dB	0 dB
19 Sept/ 10:17:47Z	40	20 dB / 4 dB	16 dB
20 Sept/ 06:03:07Z	107	30 dB / 22 dB	8 dB
06:16:50Z	93	21 dB / 21 dB	0 dB
06:46:49Z	94	28 dB / 16 dB	12 dB
13:46:50Z	91	28 dB / 15 dB	13 dB

Because of this ambiguity, if one is attempting to minimize the BER in the reception of 2400-bps data at another location, it would be essential to know what HF frequency actually optimizes the Sinad value at the receive location rather than depend on the LQA values. A review of the test data shows that when LQA values are in excess of 114 the differences in Sinad values between nodes are minimal. At 5 below this level, noteworthy discrepancies have been noted.

Also note that the algorithm for generating LQA values from Sinad and BER data has not been defined in FED-STD 1045, but has been developed and implemented independently by the Harris Corp.

From the Navy perspective, the foregoing issues are important. Navy major combatant ships use a variety of HF communication transmitters that can produce potentially high EMI levels in portions of the HF band. A shore node in a relatively EMI quiet location can bring the composite LQA up because of its high Sinad, while the ship may have a poor Sinad at that frequency as a result of the degradation caused by high shipboard EMI conditions. This can cause the selection of an HF frequency channel, based on LQA, that results in good shore reception but poor shipboard reception. NOSC has had test experience with other HF ALE systems that optimize by selecting the frequency that is good for ship reception independently from the frequency that is optimum for the shore reception. At times, excellent linkage has been noted when wide frequency separation between the nodes existed.

No advance warning on the foregoing characteristics of LQA was provided prior to the Over-The-Air testing and none appears in earlier FED-STD 1045 test reports. As a result of these findings, an attempt was made to characterize the Harris ALE controller, using the collected data, at least in its most uncomplicated conditions, namely when both ends of the links have the same Sinad value with PBER=0. The plot of figure 3-4 shows this relationship down to a Sinad value of 6 db. Below a 6-dB Sinad level, BER invariably enters the picture and causes a rapid departure from a straight line because of nonlinear weighting factors used to represent this degradation of LQA values.

The test data show that a high likelihood of linking occurs when the lowest Sinad values are equal to or greater than 6 db. From figure 3-4 it may be seen that when Sinad=6 dB at both nodes this results in an LQA=48. From the data collected, this appears to be near the lowest level where excellent Data Text Message (DTM) communication can take place. DTM uses block data transmissions that may be as short as 651 bits or up to 7,371 bits in the extended mode. The test results that follow show the significant ability of the FED-STD ALE system to receive these data at a data rate of 62.5 bps. This capability derives from the use of an excellent modulation method, transmission redundancy, interleaving, forward error correcting codes, and majority vote decision processes. Note that the ability to communicate well with direct voice modulation of the ALE selected frequency, using the full 3-kHz band, was generally poor in at least one direction but at times of very good quality in both directions. However, considering the simple whip antennas used at the Navy nodes with 100-watt RF transmitter power, the voice communications results appear to be respectable.

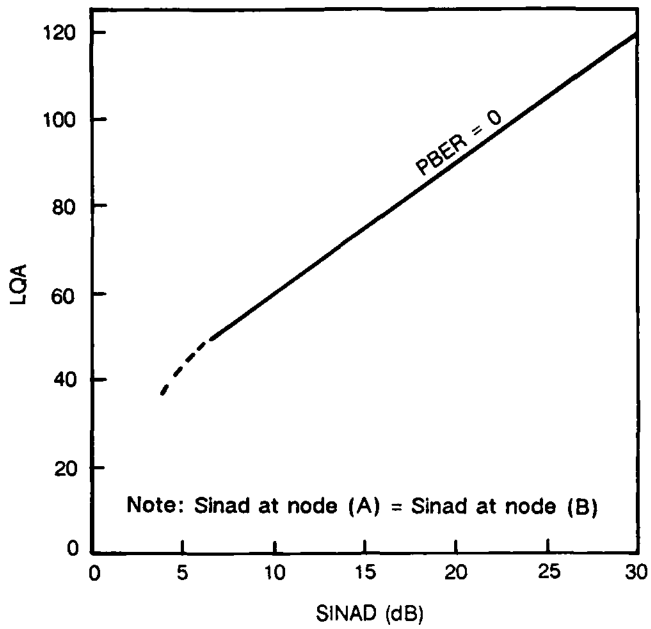

Figure 3-4. Plot of FED-STD ALE LQA versus Sinad.

Prior to discussing the graphical results, the reader is alerted to all graphical data that will be presented in this report at LQA>48. Testing results of DCA (1988) show that when using the RF 3466, 39-tone modem, 2400-bps reception could take place whenever the ALE could link (i.e., LQA>48), albeit sometimes with a high bit error. DCA (1988) stated on page 17J(2)a, "However, at a data rate of 2400 bps, the success of passing data traffic was approximately equal to the success of establishing a link with an ALE system." The data collected in this test indicate that linking always occurs at a minimum Sinad=6 dB or LQA=48. Therefore, these regions, based on DCA (1988), would permit 2400-bps data reception. Other data will be also be shown graphically revealing regions where the LQA was greater than 110 with Sinad values in the 25- to 30-dB range. These regions of high Sinad would allow 10^{-5} to 10^{-6} BER communication using the RF 5254C data modem at 2400 bps, based on Joint Tactical C^3A (1986).

3.3 RESULTS OF TEST DATA ANALYSIS

The results of the analysis of the collected test data will be presented in three basic ways in the following sections. The first presentation will show the total number of channels available for linking as a function of time of day (GMT/Z) at specified LQA levels. A second type of data presentation will show, for a particular frequency channel, what the Sinad values were for the signals measured in San Diego and Hawaii as a function of test day and time of day (GMT/Z). The third type of presentation will show the actual HF frequencies that allowed links at specified LQA values to be achieved as a function of test day and time of day (GMT/Z).

Because it had been observed earlier that a Sinad=6 dB or LQA=48 appeared to be the minimum levels where high probability of linking took place, this is highlighted in some of the graphical data presented. Similarly, because experience with the ALE system indicated that at an LQA=80 or Sinad =17 dB acceptable voice quality could be expected, this region is specifically examined in the presented data.

3.3.1 Total Channel Availability at Specific LQA/Sinad Levels Versus Time

Figures 3-5, 3-6, and 3-7 show the total number of channels available at the indicated LQA levels as a function of time. This set of three figures covers the days of Navy-Only testing. It may be noted from figure 3-5 that eight opportunities occurred on the first Navy-Only test day with LQA>110. The region in the rear of the figure represents total channels with LQA>60. It can be seen that this region is quite solid showing from three to five channels generally available for much of the time at LQA>60. From earlier discussion, it appears that this region would have allowed robust modem operation at 2400 bps with a moderate expected BER. Voice operation would have been excellent in the LQA>103 regions, with at times two channels to chose from.

Figure 3-6 shows the same parameters as the previous figure for the next test day. On this day, a substantial reduction in the available links can be observed for values of LQA>80. Also the data for LQA>60 show a noticeable drop off after a time of about 0900Z. This will be discussed later. Performance at LQA>110 is markedly poorer than that of the previous day, showing only one link opportunity.

Figure 3-7 shows the last day of the Navy-Only test. Some improvement in the quantity of links available that offer an LQA>110 is noted but still well below the first day. The region showing LQA>60 also appears stronger than the previous day in certain time periods.

Figures 3-8, 3-9, and 3-10 present the total channel performance of the ALE equipment at LQA>48 (DTM) and LQA>80 (Voice) operation. From figure 3-8, for the first Navy-Only test day, it can be seen that there were at most three 15-minute intervals in the 2230 to 1345Z period when a link did not exist that was capable of passing DTM traffic or 2400-bps modem data (refer to section 3-2 for clarification). At times there were as many as five to seven channels available to select from to support a LQA>48 capability. On the other hand, good voice reception should have been achievable over the test period as shown by the LQA>80 plot. The results shown for the next day (figure 3-9) allow similar conclusions to be reached. Figure 3-10 shows that on the last day a substantial loss in the LQA>80 region between 0800 and 1230Z.

Figure 3-11 is a different plot of the data from the first test day than shown in the previous figures. In this figure the ordinate is the value of measured signal plus noise to noise in dB (Sinad) for a single channel, namely, channel 5. The data plot that is closest, as one views this figure, gives the Sinad, as measured in Hawaii, of the San Diego transmitted signal. The plot shown in the rear of figure 3-11 is for the Sinad of the Hawaii signal as measured in San Diego. This type of presentation, for this test day, shows a general similarity between the Sinad levels at both receiving nodes, especially at high values of Sinad. From the period 0130 to 1230 on this first Navy-Only test day, note that the inability to link occurred only three times on channel 5 (0330, 0745, and 0945Z). Very high Sinad values occurred at both nodes on four occasions (25 to 30 dB).

At about 0815, a serious disparity existed between the two nodes with the Sinad on the San Diego signal being 10 to 15 dB below the Sinad on the Hawaii signal.

The same data analysis on channel 5 for the next test day showed a remarkable change, as seen in figure 3-12. The period 0830 to 1130Z (figure 3-11) showed high Sinad values for the previous day, with only one instance of an inability to link. This second day shows in figure 3-12, during this same period of about 3 hours, no linking occurred at all. In figure 3-12, the regions after 1130Z show extremely strong signal strengths at both nodes. This represents a remarkable change from the 3-hour no linking condition that immediately preceded this high Sinad condition.

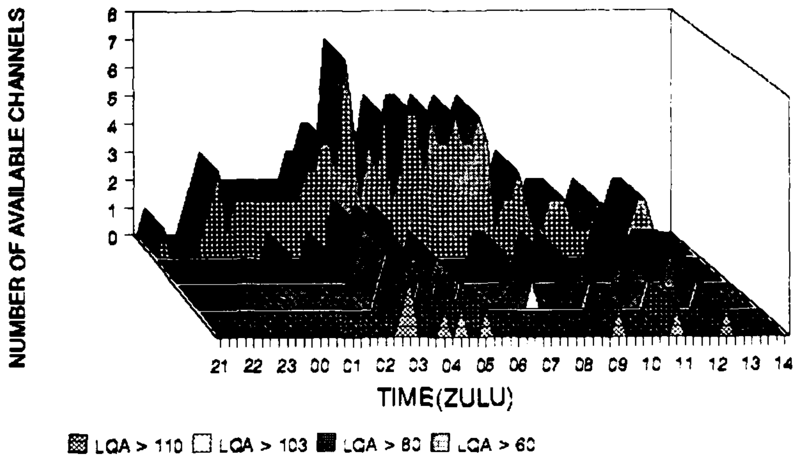

Figure 3-5. Number of available channels versus time 17/18 Sept 1990.

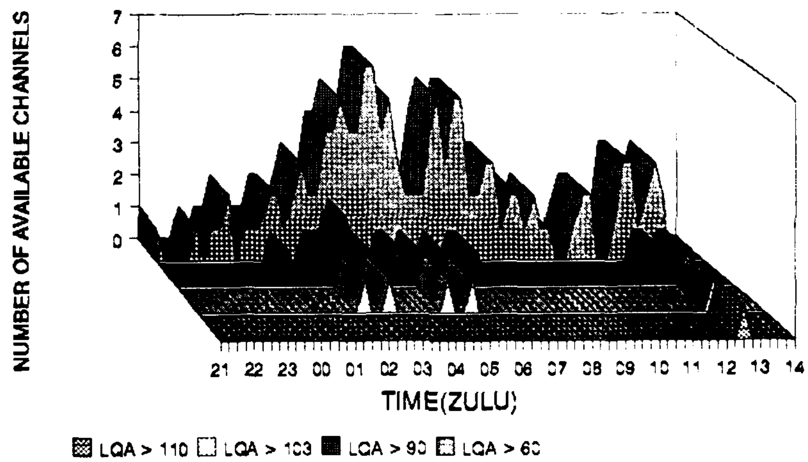

Figure 3-6. Number of available channels versus time 18/19 Sept 1990.

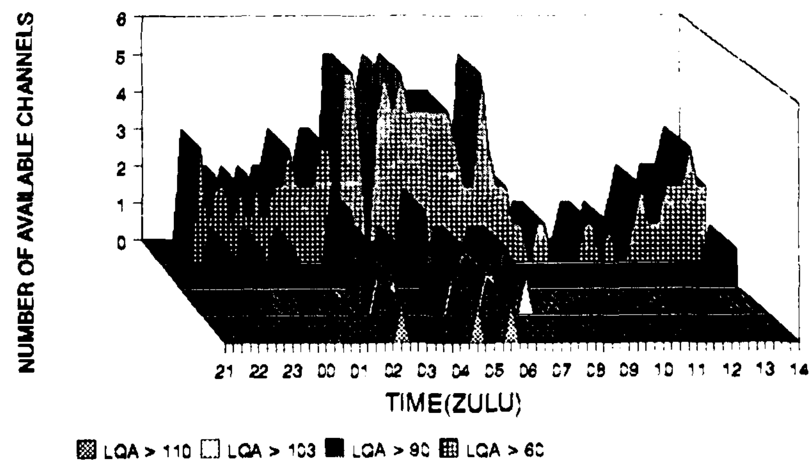

Figure 3-7. Number of available channels versus time 19/20 Sept 1990.

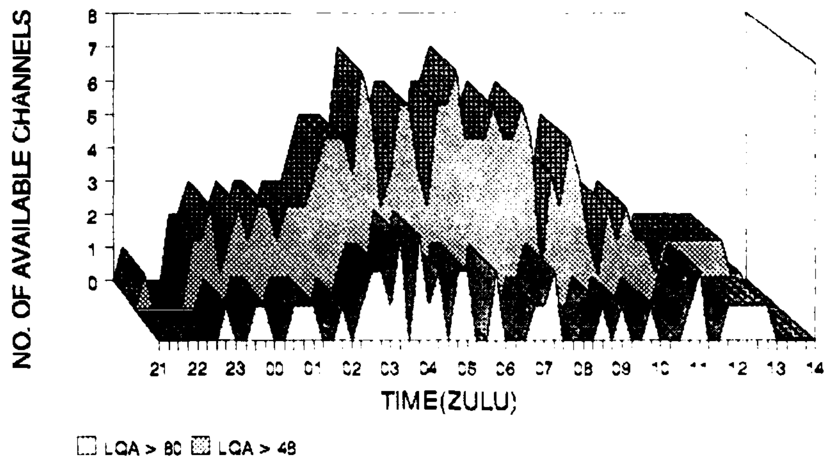

Figure 3-8. Number of available channels versus time 17/18 Sept 1990; LQA>48, LQA>80.

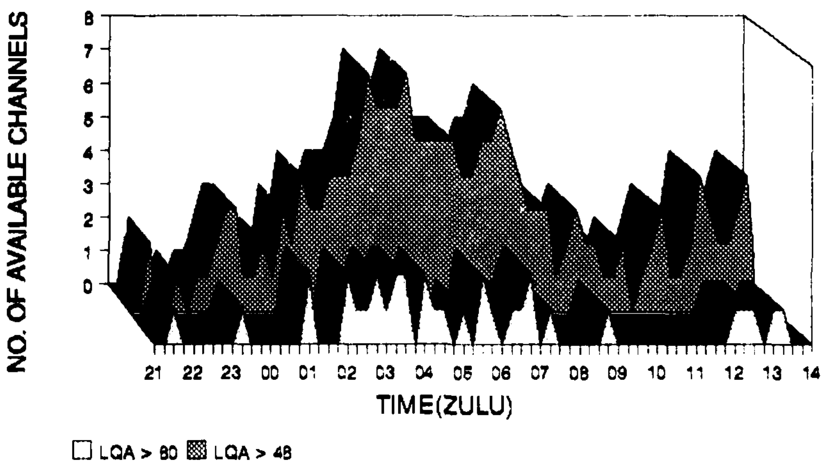

Figure 3-9. Number of available channels versus time 18/19 Sept 1990; LQA> 48, LQA >80.

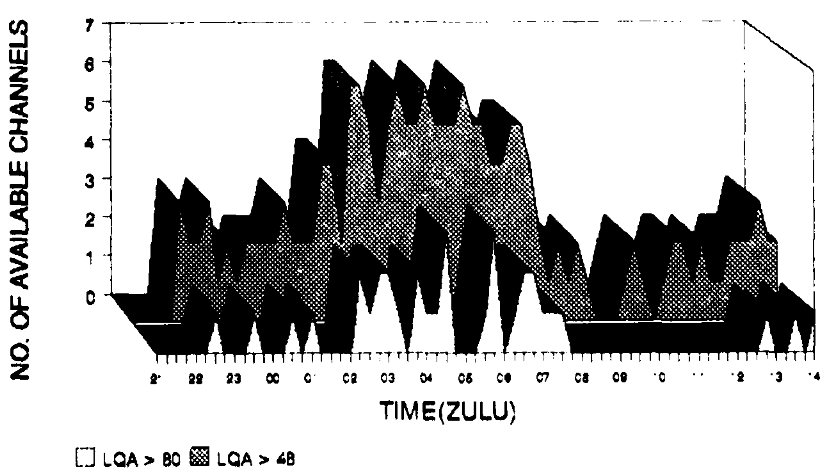

Figure 3-10. Number of available channels versus time 19/20 Sept 1990; LQA> 48, LQA> 80.

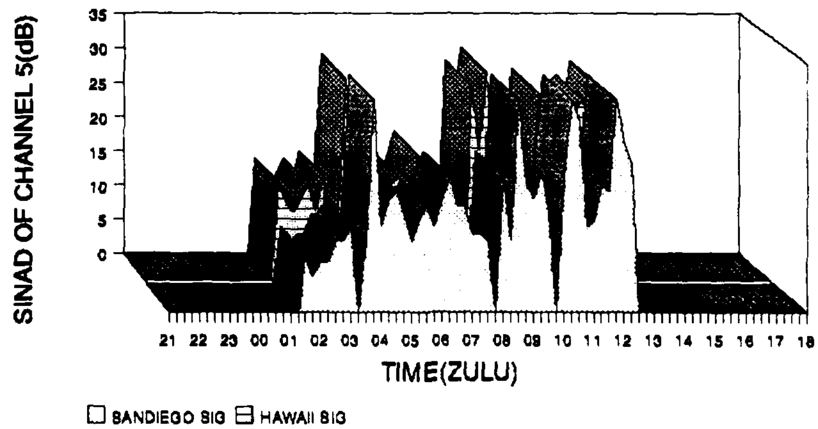

Figure 3-11. Sinad on channel 5 versus time 17/18 Sept 1990.

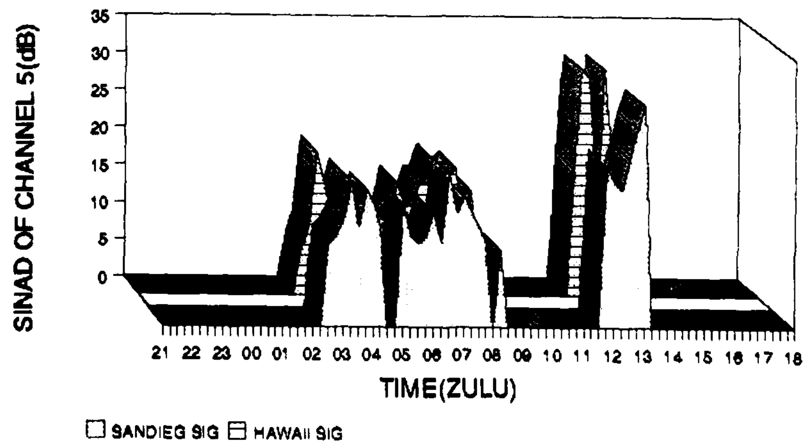

Figure 3-12. Sinad on channel 5 versus time 18/19 Sept 1990.

Figure 3-13 again uses the same data presentation for the data collected on channel 5, the third test day. These data show a several hour gap in linking, in essentially the same period as earlier, except for a spike that revealed a single link had occurred at about 1000Z (midnight in Hawaii). The levels of the Sinads for this single link are about 10 dB different between the two nodes. The lowest Sinad value was that of the San Diego signal, measured in Hawaii at about 12 dB. Except for this one single link, all other Sinad data in figure 3-13 showed the reverse, i.e., the Sinad on the San Diego signal was higher than the Sinad on the Hawaii signal. These data suggest that during the nonlinking period of 0830 to 1130Z, the Hawaii receive system was exposed to sufficient RF interference to cause the San Diego signal to drop below the threshold required for linking. Under these circumstances, even though the Hawaii signal received in San Diego may have remained at a high level, a link could not be established. The single link that was established in the middle of the extensive nonlinking period, as shown in figure 3-13, suggests that the RF interference did not exist, or was significantly reduced for the few minutes it took for this one link to be established. Immediately after this link occurred, the RF interference increased again and prevented linking in the remaining period (1000 to 1115Z). Because the Hawaii signal plot is in the rear of figures 3-11, 3-12, and 3-13, it is useful to more fully illustrate the foregoing discussion to show this plot separately. This is shown in figures 3-14, 3-15, and 3-16. Figures 3-15 and 3-16 appear to vividly display the foregoing phenomenon.

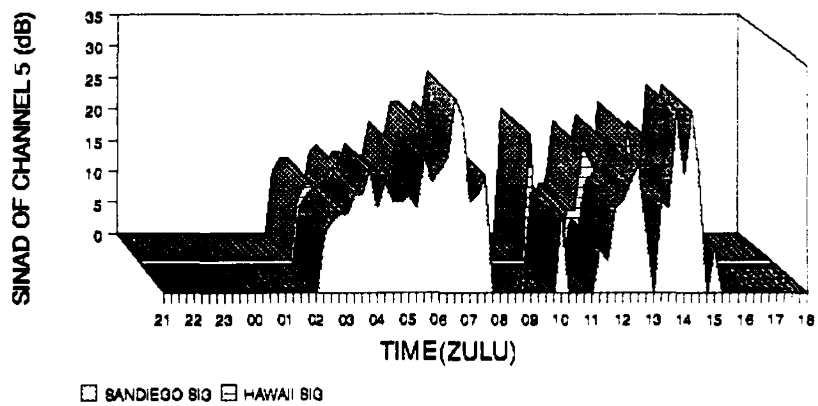

Figure 3-13. Sinad on channel 5 versus time 19/20 Sept 1990.

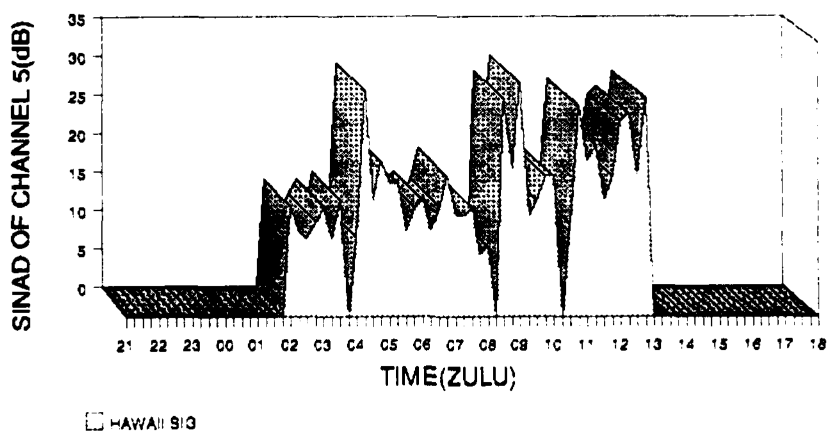

Figure 3-14. Sinad on channel 5 versus time 17/18 Sept 1990 Hawaii signal measured in San Diego.

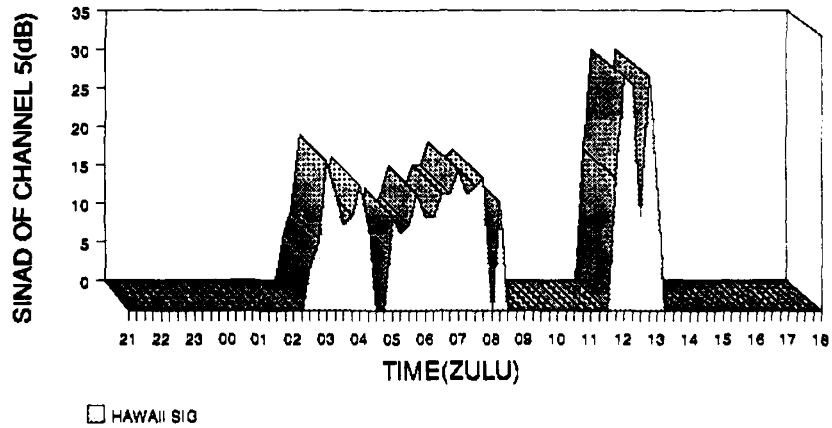

Figure 3-15. Sinad on channel 5 versus time 18/19 Sept 1990 Hawaii signal measured in San Diego.

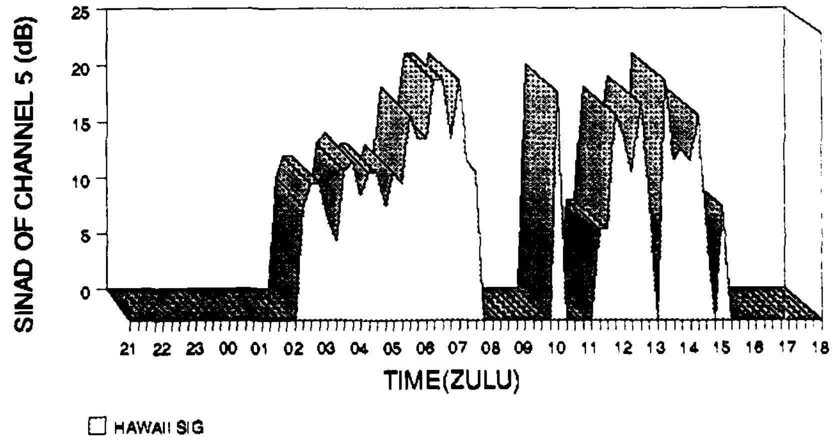

Figure 3-16. Sinad on channel 5 versus time 19/20 Sept 1990 Hawaii signal measured in San Diego.

3.3.2 Channel/Frequency Support of DTM and Voice Communications Versus Time, Over Three Test Periods

3.3.2.1 Channel Support for DTM and 2400-bps Data Transfer. Figures 3-17, 3-18, and 3-19 were developed for each test day to show the extent to which each of the 10 available HF frequencies supported links with an LQA>48. To allow a better visualization, the frequency versus time region for LQA >48 is shown within an envelope in these figures. However, even within this envelope there will be seen regions where linking was not possible. A few minor regions are shown also bounded to highlight where additional linking could occur. These data, although in appearance similar to propagation plots, reflect a good deal more since the local received noise is also included in the determination of Sinad values. These contours represent boundaries of communication system performance limits. As one moves along in time, one can see the changing support role various channels or frequencies provide. In the 2200 to 0100Z time period, it can be seen from figure 3-17 that channels 8, 9, and 10 offer support, with 8 and 9 being the main supporters. After about 0400Z, both channels 9 and 10 drop out and channels 4, 5, 6, 7, and 8 are the strong supporters. After about 0900Z, channel 5 provides far greater support than any other channel, with channels 4, 6, and 7 virtually out of the link support picture.

Between 1300 and 1400, no linking was possible on any of the 10 assigned frequency channels. What is very impressive about the data shown in figure 3-17 is the high degree of consistent support provided by certain channels. For example the data on channel 8 shows that from 2215 to 0730Z, about 9 hrs 15 minutes, there was only one instance, over a 15-minute period, that channel 8 could not support a link with an LQA>48. Stating this another way, it appears that except for this 15-minute interval virtually noninterrupted error-free DTM communications could have been achieved. Also, 2400-bps data communication could have been achieved, although at times with a high BER. The data communication at the 2400-bps rate would require a robust data modem (e.g., RF 3466) and minimal disparity in Sinad values at each node.

Channel 5 shows near continuous support starting at 0200Z to 1245Z, or 10 hours 45 minutes. There were five 15-minute periods of no link conditions at an LQA >48. Channels 1, 2, and 3 provided little to no support. The HF frequency for channel 5 was 10.423 MHz and channel 8 was 18.178 MHz. It is useful to compare these data for channel 5 with the data presentation of figure 3-11. The data for figure 3-11 can be viewed as a vertical axis of Sinad values at right angles to the channel 5 plot in figure 3-17 with a common time axis. In this way, the actual variations in Sinad and LQA>48 become more apparent.

Figure 3-18 presents the results for Navy-Only test day two. The results are, generally, similar to the earlier day, although in some instances not nearly as good. Channel 6 is significantly improved, but as noted while discussing figure 3-12, channel 5 performance abruptly ends at about 0830Z and resumes link support at 1145Z. This support continues until 1315Z, at which time it ceases. This was vividly displayed on figure 3-12 and was attributed to RF interference affecting the ALE receive system in Hawaii. Figure 3-12 displays more significantly the seriousness of the situation because it shows how high the Sinad values jumped immediately after the interference ceased. In figure 3-18, channel 5 was at least at the 6-dB Sinad level after the interference was stopped. Figure 3-19 shows the increases in the linking support provided by channels 4 and 6 late in the test period.

3.3.2.2 Channel Support of Good Quality Voice Communications. Figures 3-20, 3-21, and 3-22 present the test data in the same manner as in the previous section. The major difference is that these data are for an LQA>80 instead of 48. A level of 80 relates to a Sinad=17 for balanced link conditions and audio voice reception is expected to be of good quality.

Figure 3-20 for test day one shows that an attempt to provide boundaries at LQA >80 was a difficult task because of the predominance of conditions that would not support linking at the LQA>80 level within the boundary. However, a few points are of interest. Channel 10 shows a 1-hour period of solid support for good voice reception quality level. Channel 9 provides four 15-minute periods and a one-half hour period. Channel 8 provides good voice communication support for five 15-minute periods, two 30-minute periods, and one 45-minute period. Channels 1, 2, 3, and 7 provide no support at all. Channel 6 provides three 15-minute periods, and channel 5 provides six 15-minute periods and one 30-minute period plus one 60-minute period of link support for good voice communications. Although the link support appears very weak during this test period, if one examines the ability to achieve a usable link with any available link during each 15-minute segment, one finds that for the period from 2230 to 1300Z, or 6.5 hours, no linking was possible, but for the other 8 hours of this period, good voice communication could have been achieved. There were, at times, two or three channels available to choose from.

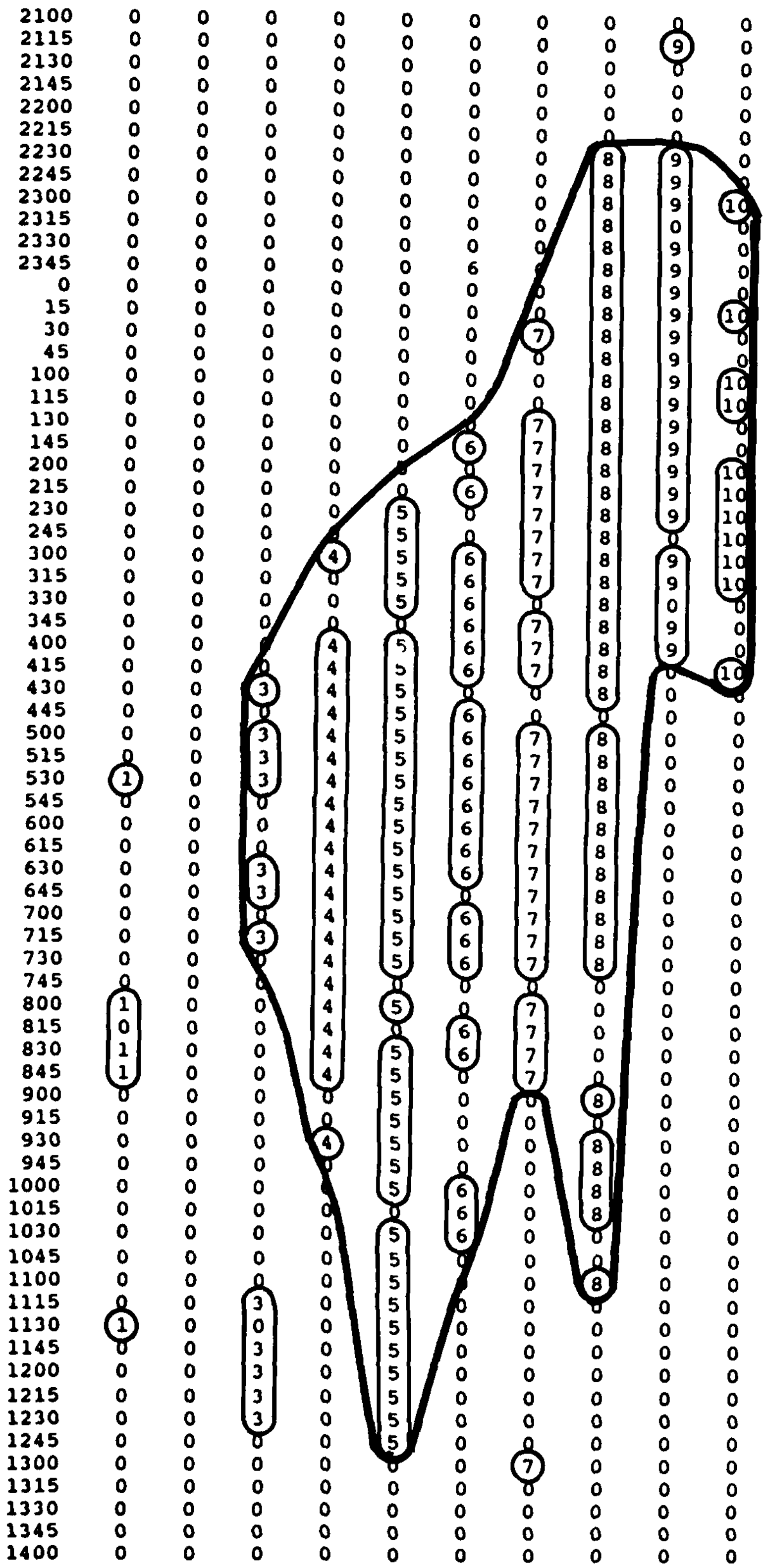

Figure 3-17. Available channels with LQA >48 versus time 17/18 Sept 1990.

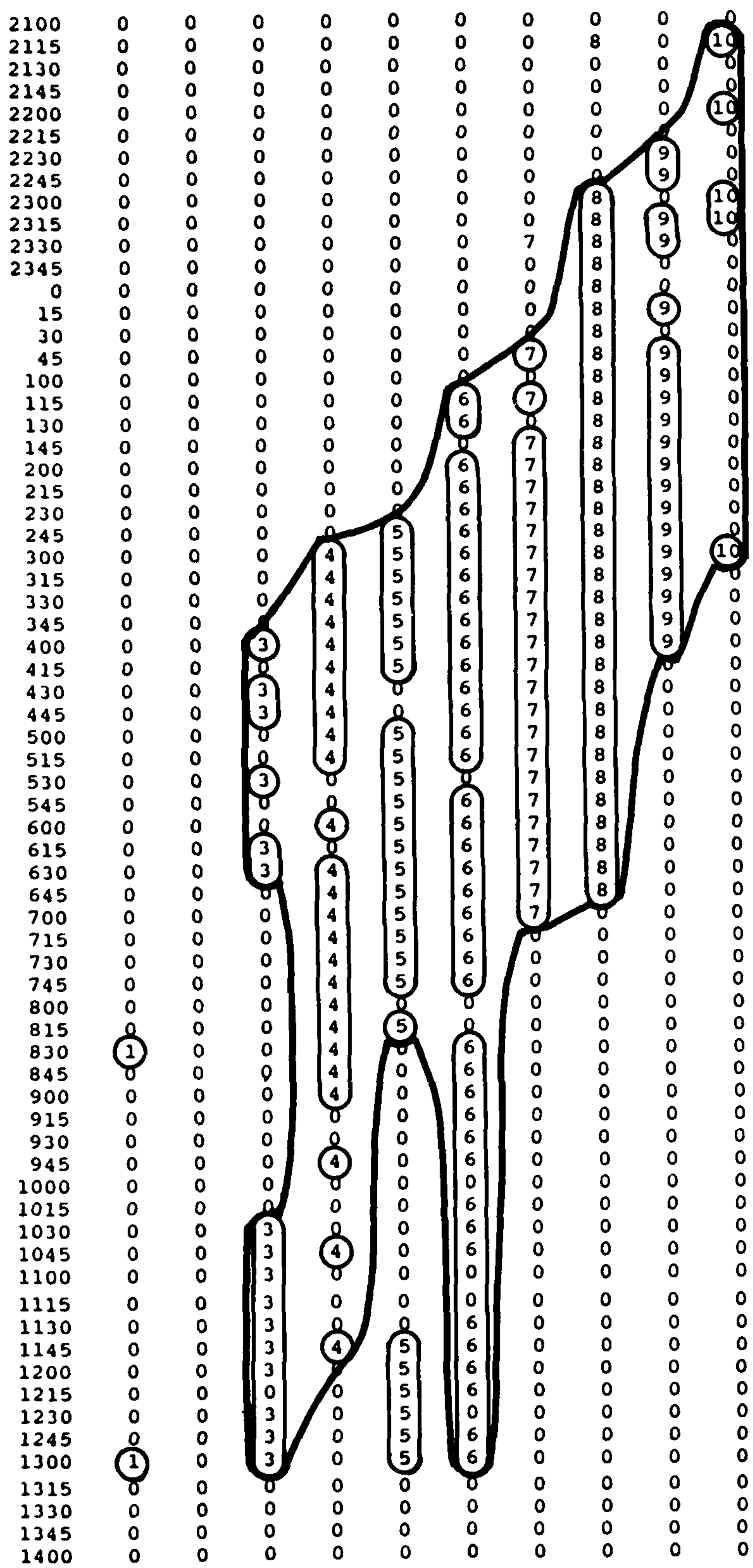

Figure 3-18. Available channels with LQA >48 versu. time 18/19 Sept 1990.

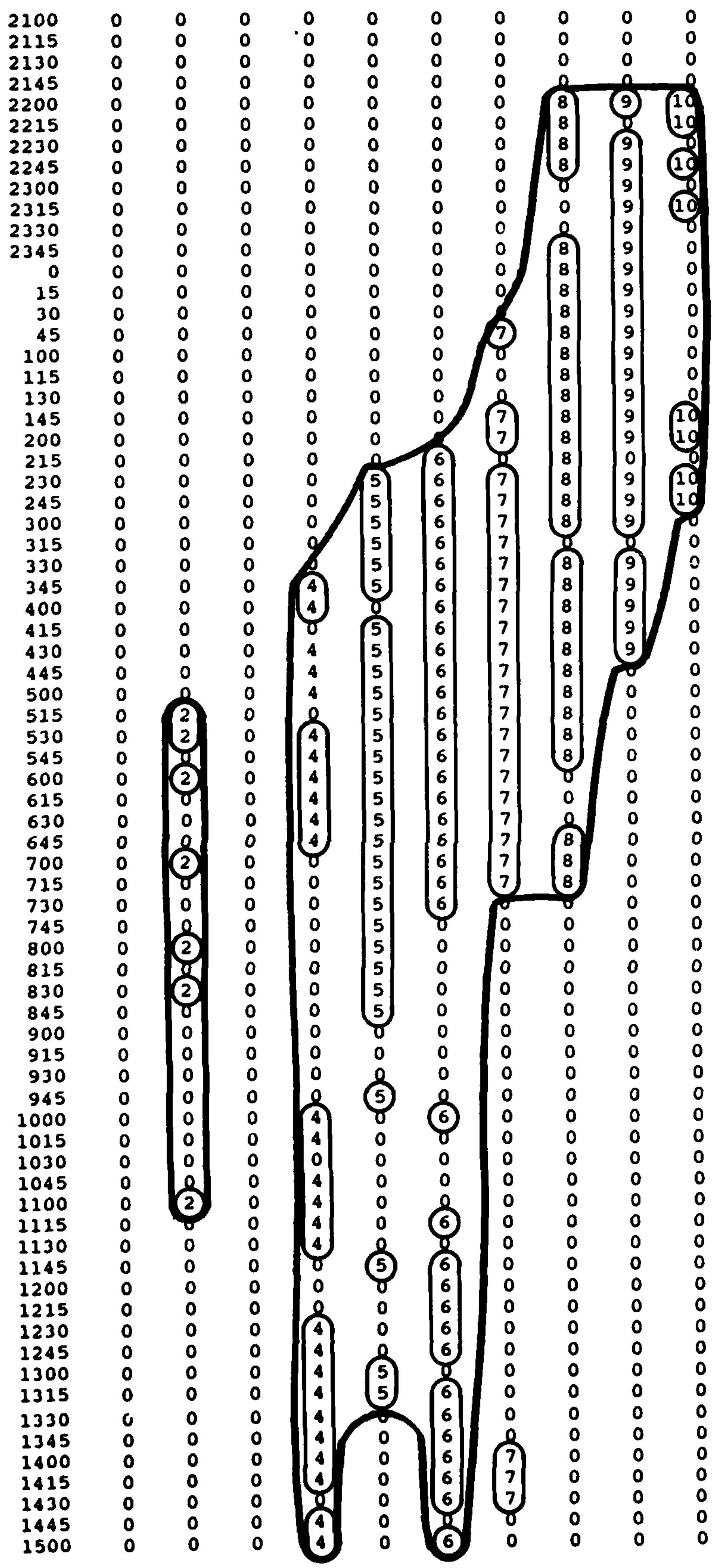

Figure 3-19. Available channels with LQA >48 versus time 19/20 Sept 1990.

2100	0	0	0	0	0	0	0	0	0	0
2115	0	0	0	0	0	0	0	0	0	0
2130	0	0	0	0	0	0	0	0	0	0
2145	0	0	0	0	0	0	0	0	0	0
2200	0	0	0	0	0	0	0	0	0	0
2215	0	0	0	0	0	0	0	0	0	0
2230	0	0	0	0	0	0	0	0	0	0
2245	0	0	0	0	0	0	0	0	9	0
2300	0	0	0	0	0	0	0	0	0	0
2315	0	0	0	0	0	0	0	0	0	0
2330	0	0	0	0	0	0	0	0	9	0
2345	0	0	0	0	0	0	0	0	9	0
0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	9	0
45	0	0	0	0	0	0	0	8	0	0
100	0	0	0	0	0	0	0	0	0	10
115	0	0	0	0	0	0	0	0	0	0
130	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	8	0	0
200	0	0	0	0	0	0	0	0	0	0
215	0	0	0	0	0	0	0	0	0	10
230	0	0	0	0	0	0	0	8	0	10
245	0	0	0	0	0	0	0	8	0	10
300	0	0	0	0	0	0	0	0	0	10
315	0	0	0	0	0	0	0	8	9	10
330	0	0	0	0	0	0	0	0	0	0
345	0	0	0	0	0	6	0	8	9	0
400	0	0	0	0	0	0	0	8	0	0
415	0	0	0	0	5	0	0	8	0	0
430	0	0	0	0	0	0	0	0	0	0
445	0	0	0	0	5	6	0	0	0	0
500	0	0	0	4	0	0	0	8	0	0
515	0	0	0	0	0	0	0	0	0	0
530	0	0	0	0	0	0	0	0	0	0
545	0	0	0	0	0	6	0	8	0	0
600	0	0	0	0	0	0	0	0	0	0
615	0	0	0	0	0	0	0	0	0	0
630	0	0	0	0	0	0	0	0	0	0
645	0	0	0	0	5	0	0	0	0	0
700	0	0	0	0	0	0	0	8	0	0
715	0	0	0	4	0	0	0	8	0	0
730	0	0	0	0	0	0	0	0	0	0
745	0	0	0	0	0	0	0	0	0	0
800	0	0	0	0	0	0	0	0	0	0
815	0	0	0	0	0	0	0	0	0	0
830	0	0	0	0	5	0	0	0	0	0
845	0	0	0	0	0	0	0	0	0	0
900	0	0	0	0	5	0	0	0	0	0
915	0	0	0	0	0	0	0	0	0	0
930	0	0	0	0	0	0	0	0	0	0
945	0	0	0	0	5	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0	0
1015	0	0	0	0	0	0	0	0	0	0
1030	0	0	0	0	0	0	0	0	0	0
1045	0	0	0	0	5	0	0	0	0	0
1100	0	0	0	0	5	0	0	8	0	0
1115	0	0	0	0	0	0	0	0	0	0
1130	0	0	0	0	0	0	0	0	0	0
1145	0	0	0	0	5	0	0	0	0	0
1200	0	0	0	0	5	0	0	0	0	0
1215	0	0	0	0	5	0	0	0	0	0
1230	0	0	0	0	5	0	0	0	0	0
1245	0	0	0	0	5	0	0	0	0	0
1300	0	0	0	0	0	0	0	0	0	0
1315	0	0	0	0	0	0	0	0	0	0
1330	0	0	0	0	0	0	0	0	0	0
1345	0	0	0	0	0	0	0	0	0	0
1400	0	0	0	0	0	0	0	0	0	0

Figure 3-20. Available channels with LQA >80 versus time 17/18 Sept 1990.

If one examines figure 3-5 in the region identified as LQA>80, these same characteristics can be seen. Also, it may be concluded from this figure that some of the above links could have actually provided LQA values at the top end of the scales shown, i.e., LQA>103 and >110.

Figures 3-21 and 3-22 for the second and third test day show a poorer performance than figure 3-20. This is to be expected when one views figures 3-6 and 3-7 as compared to figure 3-5. Channel 5 performance for LQA>80 link support in figure 3-21 is nonexistent from 0715 to 1130Z, at which time it jumped to a relatively steady operation at this LQA>80 level. In figure 3-22, channel 5 does not support LQA>80 after 0715Z.

2100	0	0	0	0	0	0	0	0	0	0
2115	0	0	0	0	0	0	0	0	0	10
2130	0	0	0	0	0	0	0	0	0	0
2145	0	0	0	0	0	0	0	0	0	0
2200	0	0	0	0	0	0	0	0	0	0
2215	0	0	0	0	0	0	0	0	0	0
2230	0	0	0	0	0	0	0	0	0	0
2245	0	0	0	0	0	0	0	0	0	0
2300	0	0	0	0	0	0	0	0	0	10
2315	0	0	0	0	0	0	0	0	0	0
2330	0	0	0	0	0	0	0	0	0	0
2345	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	8	9	0
100	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0
130	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	8	9	0
200	0	0	0	0	0	0	0	8	0	0
215	0	0	0	0	0	0	0	8	0	0
230	0	0	0	0	0	0	7	8	0	0
245	0	0	0	0	0	0	0	0	9	0
300	0	0	0	0	0	0	7	8	0	0
315	0	0	0	0	0	0	0	8	9	0
330	0	0	0	0	0	0	0	0	0	0
345	0	0	0	0	0	6	0	0	9	0
400	0	0	0	0	0	0	0	8	0	0
415	0	0	0	0	0	0	0	8	0	0
430	0	0	0	0	0	0	0	0	0	0
445	0	0	0	0	0	6	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0
515	0	0	0	0	0	6	0	8	0	0
530	0	0	0	0	0	0	0	8	0	0
545	0	0	0	0	0	0	0	0	0	0
600	0	0	0	0	0	0	0	8	0	0
615	0	0	0	0	0	0	0	8	0	0
630	0	0	0	0	5	0	0	8	0	0
645	0	0	0	0	0	0	0	0	0	0
700	0	0	0	0	5	0	0	0	0	0
715	0	0	0	0	0	0	0	0	0	0
730	0	0	0	0	0	0	0	0	0	0
745	0	0	0	0	0	0	0	0	0	0
800	0	0	0	0	0	0	0	0	0	0
815	0	0	0	0	0	0	0	0	0	0
830	0	0	0	0	0	6	0	0	0	0
845	0	0	0	0	0	0	0	0	0	0
900	0	0	0	0	0	0	0	0	0	0
915	0	0	0	0	0	0	0	0	0	0
930	0	0	0	0	0	0	0	0	0	0
945	0	0	0	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0	0
1015	0	0	0	0	0	0	0	0	0	0
1030	0	0	0	0	0	0	0	0	0	0
1045	0	0	0	0	0	0	0	0	0	0
1100	0	0	0	0	0	0	0	0	0	0
1115	0	0	0	0	0	0	0	0	0	0
1130	0	0	0	0	0	0	0	0	0	0
1145	0	0	0	0	5	0	0	0	0	0
1200	0	0	0	0	5	0	0	0	0	0
1215	0	0	0	0	5	0	0	0	0	0
1230	0	0	0	0	0	0	0	0	0	0
1245	0	0	0	0	5	0	0	0	0	0
1300	0	0	0	0	5	0	0	0	0	0
1315	0	0	0	0	0	0	0	0	0	0
1330	0	0	0	0	0	0	0	0	0	0
1345	0	0	0	0	0	0	0	0	0	0
1400	0	0	0	0	0	0	0	0	0	0

Figure 3-21. Available channels with LQA >80 versus time 18/19 Sept 1990.

2100	0	0	0	0	0	0	0	0	0	0
2115	0	0	0	0	0	0	0	0	0	0
2130	0	0	0	0	0	0	0	0	0	0
2145	0	0	0	0	0	0	0	0	0	0
2200	0	0	0	0	0	0	0	0	0	0
2215	0	0	0	0	0	0	0	0	0	10
2230	0	0	0	0	0	0	0	0	0	0
2245	0	0	0	0	0	0	0	0	0	0
2300	0	0	0	0	0	0	0	0	0	0
2315	0	0	0	0	0	0	0	0	0	10
2330	0	0	0	0	0	0	0	0	0	0
2345	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	9	0
30	0	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	9	0
100	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0
130	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	8	9	0
215	0	0	0	0	0	0	0	8	0	0
230	0	0	0	0	0	0	0	8	9	0
245	0	0	0	0	0	0	0	8	0	10
300	0	0	0	0	0	0	0	0	9	0
315	0	0	0	0	0	0	0	0	0	0
330	0	0	0	0	0	0	7	8	0	0
345	0	0	0	0	0	0	0	8	0	0
400	0	0	0	0	0	0	0	0	9	0
415	0	0	0	0	0	0	7	8	9	0
430	0	0	0	0	0	0	0	0	0	0
445	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0
515	0	0	0	0	0	0	0	8	0	0
530	0	0	0	0	0	6	7	8	0	0
545	0	0	0	0	0	0	0	0	0	0
600	0	0	0	0	0	6	0	0	0	0
615	0	0	0	0	5	6	0	0	0	0
630	0	0	0	0	5	6	0	0	0	0
645	0	0	0	0	0	6	0	0	0	0
700	0	0	0	0	0	6	0	0	0	0
715	0	0	0	0	5	0	0	0	0	0
730	0	0	0	0	0	0	0	0	0	0
745	0	0	0	0	0	0	0	0	0	0
800	0	0	0	0	0	0	0	0	0	0
815	0	0	0	0	0	0	0	0	0	0
830	0	0	0	0	0	0	0	0	0	0
845	0	0	0	0	0	0	0	0	0	0
900	0	0	0	0	0	0	0	0	0	0
915	0	0	0	0	0	0	0	0	0	0
930	0	0	0	0	0	0	0	0	0	0
945	0	0	0	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0	0
1015	0	0	0	0	0	0	0	0	0	0
1030	0	0	0	0	0	0	0	0	0	0
1045	0	0	0	0	0	0	0	0	0	0
1100	0	0	0	0	0	0	0	0	0	0
1115	0	0	0	0	0	0	0	0	0	0
1130	0	0	0	0	0	0	0	0	0	0
1145	0	0	0	0	0	0	0	0	0	0
1200	0	0	0	0	0	0	0	0	0	0
1215	0	0	0	0	0	0	0	0	0	0
1230	0	0	0	0	0	6	0	0	0	0
1245	0	0	0	0	0	0	0	0	0	0
1300	0	0	0	0	0	0	0	0	0	0
1315	0	0	0	0	0	6	0	0	0	0
1330	0	0	0	0	0	0	0	0	0	0
1345	0	0	0	0	0	6	0	0	0	0
1400	0	0	0	0	0	0	0	0	0	0
1415	0	0	0	0	0	6	0	0	0	0
1430	0	0	0	0	0	0	0	0	0	0
1445	0	0	0	0	0	0	0	0	0	0
1500	0	0	0	0	0	0	0	0	0	0

Figure 3-22. Available channels with LQA >80 versus time 19/20 Sept 1990.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS—GENERAL

The conclusions and recommendations are based on the Navy-Only testing performed separately from the FED-STD Over-The Air testing. The Navy-Only testing occurred in three 16-hour test periods starting on 2100Z on 17 September and ending on 1400Z on 20 September.

The FED-STD ALE equipment rapidly performed the ALE three-way handshake on the usable HF frequencies/channels. During the node-to-node, three-way handshake, Sinad and PBER data were passed on acceptable channels to permit determination of the link LQA values.

The FED-STD ALE demonstrated a remarkable capability to virtually always provide at least one and sometimes many frequency channels that would allow data transfer in its ALE data modes at a 62.5-bps data rate. On a number of occasions, NOSC San Diego was used as a DTM relay node between FEMA on the East Coast and NOSC Hawaii. The FED-STD automatic DTM relay was performed error free.

On many occasions, the operator of the ALE equipment used channels selected by the FED-STD ALE for HF voice communication between test nodes. In voice communication with FEMA, excellent voice copy was achieved in part because of the sophisticated HF antenna installation at FEMA. Generally, between the Navy nodes, attempts at voice communications using the channels selected by the ALE resulted in many instances where one node was receiving very well and the other was receiving very poorly. On a few occasions, the voice copy was excellent at both Navy nodes. These observations are in accord with the data plotted in figures 3-20, 3-21, and 3-22 for LQA>80 associated with a balanced Sinad>17 dB. A more sophisticated HF antenna system plus use of 500- to 1000-watt PA would have improved voice performance. A disparity in Sinad values between the nodes would explain imbalance in nodal performance for voice or data operation.

4.1.1 Conclusions Regarding Navy Operational Use of FED-STD ALE

4.1.1.1 Operational Support Possibilities for High Data Rate Communication—2400 bps Using FED-STD ALE. Previous testing by JITC, reported in DCA (1988), concluded that the Harris 3466 robust modem could pass 2400-bps data traffic any time ALE could link. Analysis of the Navy test data showed a high probability of linking anytime both nodes had a Sinad>6 dB. In this IED report, an idealized correlation was developed between Sinad and LQA (figure 3-4) . On this basis, a Sinad of 6 dB coincides with an LQA value of 48. Therefore, the portion of figure 3-8 that refers to LQA>48 reveals virtually solid linking capability when using all available channels. Viewed differently, this also is the region that would permit 2400-bps data reception capability when using the RF 3466 robust modem. Figure 3-5 allows a more refined examination of this point. This figure shows in the rear the number of links that could support LQA>60 for the same test day. The available channels are not, in general, greatly reduced from that shown for LQA>48 in figure 3-8. Therefore, a great deal of what is shown for LQA>48 in figure 3-8 actually are channels that will allow LQA>60 with some links even at the LQA>110 level. Nevertheless, based on the JITC report for an LQA range, 48<LQA<60, the BER at 2400 bps might still be unacceptable. However, the remaining large number of channels for LQA>60 of figure 3-5 might provide generally acceptable BER at 2400 bps.

Note that the foregoing assessment has not addressed the technical questions related to the switching of the modem from one link to another to maintain continuous data flow while minimizing BER.

4.1.1.2 Application of FED-STD ALE in the Navy Shipboard Electromagnetic Interference Environment. The major issue to be faced in any attempt to use the FED-STD ALE aboard a Navy major combatant ship is the collocation of the ALE receive system with an already large number of various HF transmitters creating a crowded electromagnetic spectrum. The Navy-Only test results contained in this report were obtained at two generally (EMI) quiet shore locations. On a major combatant ship, there will be RF broadband transmitter noise energy, transmitter intermodulation (IM) distortion products, and adjacent signal interference from various sources showing up over the HF spectrum. There will also be various HF transmitters attempting to find good HF frequencies, while others may be up operating wideband data or in voice nets. If one attempts to ignore the resulting HF interference across the HF spectrum, one may discover it is not possible to achieve any FED-STD ALE LQA calls, as occurred at times during the Navy-Only test. This problem is accentuated in the design of the FED-STD ALE because it allows only one frequency to be selected for a link between two nodes. The limited number of good shipboard HF receive frequencies that may exist, because of shipboard EMI, will therefore restrict the range of transmit frequencies that the shore node may use. Because of the single frequency LQA/linking in the FED-STD ALE, the set of shore receive frequencies also will be restricted to these same frequencies. Figures 3-11, 3-12, and 3-13 show the effects of EMI in preventing linking even in a purely shore EMI environment. In the case discussed, it was concluded that RF interference on channel 5 occurred at the Hawaii node and raised the received noise level above the signal reception threshold. Consequently, in a certain time interval the three-way handshake could not be performed on channel 5. Since a Sinad data exchange could not take place between the nodes, linking in this period could not occur on channel 5, while it could occur on channels 3, 4, or 6, as shown in figure 3-18.

It is concluded that the use of the FED-STD ALE on major Navy combatant ships would be significantly enhanced if the ALE could make separate selections of the best HF frequency for each direction. If this was implemented, the disparity seen in the Sinad test data relative to LQA, as cited in this report, would be eliminated. When complete receive frequency selection flexibility is allowed, each frequency decision would be based only on the Sinad for the received signal on each path. From the test data, it appears that Sinad=10 dB and Sinad=17 dB would be acceptable levels at each node for DTM data and voice communications, respectively. Since in this range it is doubtful that PBER has a significant effect on LQA, it appears that Sinad determination may be all that is required. Also, this change would functionally allow full duplex data exchange between ship and shore, with a separate transmitter and receiver at each node operating under enhanced ALE control.

4.2 RECOMMENDATIONS

If the Navy is to benefit from the current developments in FED-STD ALE technology, it should either

A. Attempt to have a special Navy mode installed in the present FED-STD ALE that will allow independent HF transmit/receive frequency selection at each node. The frequency selection would be based only on the Sinad value at each receive node. The Sinad measurement of the received signal would be done just as in the present FED-STD ALE. Or,

B. Contract with an HF/ALE manufacturer to obtain the needed capabilities in a specialized HF/ALE for Navy major combatant ship applications. If this course is chosen, consideration should be given to including a frequency hopping option in the new ALE design.

5.0 GLOSSARY

ALE	Automatic link establishment
BPS	Bits per second
CIA	Central Intelligence Agency
C^3I	Command, control, communications, and intelligence
DCA	Defense Communications Agency
DTM	Data text message
dB	Decibels
EMI	Electromagnetic interference
FED-STD	Federal Standard
FEMA	Federal Emergency Management Agency
FSK	Frequency shift keying
GMT	Greenwich mean time
HF	High frequency
IED	Independent Exploratory Development
ITS	Institute of Telecommunications Sciences
JITC	Joint Interoperability Test Center
KHZ	Kilohertz
LQA	Link quality assessment
MHz	Megahertz
MIL-STD	Military Standard
NSA	National Security Agency
NRL	Naval Research Laboratory
PI	Principal investigator
PTP	Point to point
POC	Proof of concept
PBER	Psuedo bit error rate
RF	Radio frequency

SINAD	**Signal plus noise to noise ratio (dB)**
TDM	**Time division multiplex**

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This report documents the Navy's participation in Federal-level Automatic Link Establishment (ALE) standards development and related test and evaluation planning for testing these standards. Over-The-Air Federal testing of the 1990 Federal Standard (FED-STD) 1046 (networking) and 1049 (link protection) was supported by the Naval Ocean Systems Center (NOSC). Concurrent with this testing, NOSC conducted Navy-Only tests of the ALE controller that has been designed and developed in accordance with ALE FED-STD 1045. This report presents the results obtained from this series of Navy-Only tests together with a set of recommendations and conclusions related to Navy application of FED-STD ALE for the improvement of high frequency communications.

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